Inter-Device Reliability of the BodPod for Clinical and Research Use

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Abstract

Air-displacement plethysmography (ADP) by the BodPod device is an increasingly popular instrument for determining body composition for both clinical and research applications. Despite previous studies, the reliability of ADP devices remains controversial and few studies testing inter-laboratory measurements exist. At our institution, we have the unique opportunity to have three BodPod devices located in individual laboratories providing the opportunity to investigate this reliability. The purpose of the study was to test the reliability of inter-device ADP measurements of body composition by the BodPod. The study population consisted of a convenience sample of twenty-one young women ages 18-30 years old. This cross-sectional study examined the inter-laboratory reliability of body fat estimates by performing successive measurements using BodPods in each of three campus laboratories on the same day within a two hour period. A counterbalance design was used to determine the location order of measurements. The inter-laboratory reproducibility of body fat was determined in order to examine whether the results from each of these three devices can be used interchangeably for clinical and research applications. The study also measured relative humidity and room temperature for each session to analyze the possible influence on error between measures. Two of the three BodPods yielded similar results, while the third BodPod was +1.7-1.8% different in body fat. The conclusion of the study was that the BodPod needs to be in a stable environment for reliable measures, and it suggested that clients use a single device for serial measures.

Introduction

The BodPod or air-displacement plethysmograph (ADP) is an increasingly popular instrument for determining body composition in both clinical and research applications. Despite previous studies, the reliability of ADP devices remains controversial [1], and few studies testing inter-laboratory measurements exist. At our institution, we have the unique opportunity to have three BodPod devices located in individual laboratories providing us the unique opportunity to investigate reliability. Through a specific clinical application in which a subject was measured in one BodPod and subsequently in another BodPod, a 6% discrepancy for percent body fat estimates was observed and indicated that the reliability of the systems across the institution should be studied. These machines are used clinically as the primary method of measuring body fat in university athletes and are being touted as highly accurate.

The primary aim of this study was to compare the inter-laboratory precision in body composition measurements from three BodPod devices located in three different OSU laboratories. There is a distinct advantage to collecting measurements for the three devices in different labs as opposed to comparing them in the same lab as this is more representative of the situation in which clients obtain measures from more than one BodPod. The inter-laboratory reproducibility in body fat was determined in order to examine the reliability of the BodPod device for both clinical and research applications. An secondary aim of the study was to identify the potential environmental factors that may influence variation in outcomes.

ADP

The BodPod is based on similar volume principles of hydrodensitometry, and uses an air displacement plethysmograph (pressure sensing diaphragm) to estimate body volume. As part of the manufacture's protocol, mass is measured on the digital scale provided by and integrated with the ADP system. Based on Boyle's law, the relationship between pressure and volume allows for the estimation of body volume based on pressure changes inside a known chamber. Volume estimations are then combined with mass to yield body density (Db=volume/mass). Body density is then used to estimate percent body fat (BF) using a population-specific equation, such as the Siri equation for a general athletic population.

Details regarding further physical concepts and operational principles of ADP are reported [2, 3], but the machine is fairly simple. The standard test procedure consists of two uncorrected body volume measurements. When these two values are within the predetermined limit set by the manufacturer of 150 mL, the mean value is used by the instrument software for subsequent calculations of corrected body volume, body density and body composition [1]. When the difference of the measures exceeds 150 mL, the machine requires a third measurement to provide a better mean air displacement. The algorithm of the machine adjusts the body volume for thoracic gas volume, determines body density using weight, then applies the Siri equation to estimate body composition. The operation of the BodPod system should follow the manufacturer's specifications for use (see Table 1) [4].

Table 1 Manufacturer's Operating Specifications for Use

Temperature	**Relative Humidity**
70-80 (°F)	20-70%
• Do not operate in room where temperature is not constant.	
• Do not place near a heater, air conditioner, or fan.	
• Do not place near a door that may be opened or shut during testing.	

Background

Many studies have determined the strength of reliability of the methods of body composition assessment including comparisons of ADP to other methods of body composition testing, including dual x-ray absorptiometry (DXA), hydrostatic weighing, and/or anthropometry-skin fold measurements [4-10]. One study comparing ADP to DXA found that ADP percent body fat (%BF) was highly correlated with DXA %BF ($r^2 = 0.92$) [4], while others found significant correlations between ADP and hydrostatic weighing with $r^2 = 0.93$ [3], $r^2 = 0.89$ [11], and $r^2 = 0.94$ [12]. The reported biases in body composition estimates are generally small, lending to the increased use of ADP as an alternative to other methods of body composition assessment. Due to its convenience and ability to enhance subject compliance and acceptance, the BodPod method has many advantages over the 'gold standard', hydrostatic weighing.

Several studies have been conducted to determine intra-laboratory reliability (same lab, same machine) for both same day measurements [1, 13-15] and reliability of trials performed over more than one day [13, 16]. Previous studies have reported that intra-device reliability indicated by within-subject coefficients of variation for repeated measurements by a single BodPod within a day of 1.7% body fat [3], and 2.3% body fat [13] for single measurements between days in adult subjects. A study by Anderson used two trials per day to test intra-device reliability over three days and found standard deviation for body volume to be 0.329 L (0.176-0.608 L) [16]. While body volume is the primary estimate of the BodPod that leads to the %BF estimate, it is likely more clinically relevant to look at the %BF estimates. The aforementioned body volume values translate to standard deviation in BF equivalent to 1.10% (0.24-3.4%) with a coefficient of variation of 5.30%. Results of the Anderson study indicate significant differences in between-day estimates of BF using ADP [16]. These intra-laboratory reliability studies demonstrate the error in %BF, as determined by trials, is in accordance with the 2% error set forth by the manufacturer LMI (Life Measurement, Inc.) [4].

Two studies have tested inter-device variability of body fat estimates (different labs and/or different machines). A study by Ball performed duplicate body composition tests on subjects (n=50) in succession using two ADP devices located in the same laboratory [17]. Thoracic lung volume was *measured* in this protocol. Ball found no significant differences in body density for men, but a significant difference in body density between the two devices for women (0.00187 ± 0.0003 g/ml, $P < 0.001$). These results translated into a significant difference for women in %BF estimates between the two devices ($0.8 \pm 1.1\%$, $P < 0.001$) [17]. Ball reports a disparity between genders for BF outcomes, and suggests a possible explanation that the range of body fat for female subjects (13-43%) was greater than the range of the male subjects (12-32%) which may have resulted in a higher random error in the BF estimates [17]. While it was an advantage in this study for both BodPod units to be in the same laboratory in order to control for environmental factors, the major limitation of this study is that in a clinical scenario, the ability to control environmental factors across BodPod laboratories is highly unlikely.

Another inter-device study by Collins *et al* (2004) tested the variability of two devices between two different laboratories [1]. The standard deviation for body volume was 250 ml with

relatively large 95% limits of agreement for %BF (-3.7 to 2.5). Unlike the study by Ball, this study used the *predicted* thoracic lung volume selection. The environmental factors, ambient air temperature and atmospheric pressure, were measured in order to identify any influence on variation between the two labs. Collins suggested that environmental differences, namely temperature, between the two laboratories may have caused the observed %BF differences [1]. Both inter-device reliability studies concluded similarly that inter-device variability between multiple BodPod units is as good as within one unit, but Collins further recommended that practitioners should use caution when multiple units are being used for comparison [1].

Many studies have determined the strength of reliability of body composition assessment by BodPods when compared to other methods of body composition testing. The examinations of intra-device BodPod precision show %BF estimations are in accordance with LMI standards (i.e., within 2% BF). Aside from the Collins study which attempted to determine the possible influence on machine error due to temperature and pressure variables, few studies have examined what environmental factors contribute to observed machine error. Quantification of the influence of these factors on BF estimates as well as the determination of the reliability of measures between BodPods has not been adequately addressed. BodPod reference manuals indicate specifications for relative humidity (RH), yet the influence of RH on BF estimates has yet to be identified. The influence of relative humidity as well as temperature should be investigated in order to further determine potential covariates in reliability of measurements. Additionally, the examination of inter-device reliability of BodPods using more than two devices is an advantage over previous studies.

Materials and Methods

Subjects

Subjects were a homogenous convenience sample of twenty-one women ages 18-24 years old with a BMI of 17.6 to 25.6 kg/m^2. The inclusion criteria were designed to support a homogenous investigation by limiting the amount of variability due to a large range of body fat in subjects. Subjects were recruited via word of mouth and fliers through the Labs in Life community of student volunteers and a limited number from academic courses. The experimental

procedures were approved by the Human Subjects Institutional Review Board of The Ohio State University (Protocol 2010H0046). All subjects gave written, informed consent prior to data collection.

Protocol

All subjects were asked to arrive for testing after an approximate 2-hour fast from eating, drinking, or exercising. Subjects were asked to void prior to the first measurement in order to limit further voiding as a possible confounder. During testing, no subject had the need to void or eat/drink. The clothing and cap worn by each subject was held constant for each individual for all measurements taken. Subjects were dressed in minimal, skin-tight clothing or one-piece swim suits worn for the duration of all measures in order to minimize differences due to clothing or heat dissipation issues. Subjects were transported between labs with limited walking to effectively limit increased heat dissipation or further dehydration as potential confounders. To avoid the possibility of introducing a systematic error, the order of measurements on each group of 2-3 individuals was counterbalanced to ensure fasted state variation for successive measurements was randomized.

Successive measurements were performed using BodPods in each of three laboratories within close proximity: Labs in Life (LIL), COSI, Center for Clinical and Translational Science (CCTSS), OSU, Woody Hayes Athletic Center (WHAC), OSU. LIL and WHAC devices are BOD POD 2007A Gold Standard models, while CCCTS was an older Gold Standard BodPod model that runs on the DOS system with Version 2.14 Software. Individual subject testing was completed within a two hour period on the same day and generally between ten a.m. and noon. The two trained technicians followed the manufacturer and software protocol for all measurements. Ambient temperature, relative humidity, and wet bulb were recorded using a standardized digital psychrometer at each session. The digital psychrometer (UEI model DTH31) is rated ± 3% RH accuracy and ± 1 °F temperature accuracy. The BodPod is claimed to accommodate for environmental settings within the manufacturer's specifications, but measurements were made in an attempt to identify any environmental influence on reliability, and to determine whether each lab maintained an environment in compliance with manufacturer's specifications.

Full calibrations on the scales according to manufacturer's guidelines were performed on each machine daily prior to subject measurements. The software protocol calls for additional calibrations of the internal compartment of the BodPod using the volumetric cylinder for each individual measurement. Body weight was measured as part of the machine protocol using the scale. The height input variables were standardized between measures for each subject by measuring height to the nearest 0.1 cm using the stadiometer located at the CCTS site for each subject during the consenting process. The subject information input into the set up panel included subject number, birth date, selection of the predicted thoracic gas volume setting, standardized height, female, general population ethnicity indicators, and selection of the Siri equation.

Statistical Analysis

Data were exported from each BodPod machine into excel, trimmed and imported into SAS version 9.2 for analysis. The a priori level of statistical significance was $P < 0.05$. Data were modeled using general linear modeling procedure as repeated measures data from each subject. The influence of lab site was analyzed as the primary independent variable of interest to predict percent body fat. The normal distribution assumption underlying the model was checked by saving the model residuals and plotting for normal distribution. This same model was evaluated for the possible influence of relative humidity, room temperature, and technician as covariates. For completeness of evaluation, body weight and body density were also evaluated similarly as dependent variables for differences between labs.

Results

The researchers recruited and consented 21 subjects with average BMI of 22.1 kg/m^2. The ranges of observed subject age, height, and measured body weight were 18-24 years, 152-182 cm, and 50.8-71.5 kg respectively. Original research design was to only include subjects with BMIs of 20-30 kg/m^2, however, we did accept volunteers lower than the original inclusion criteria (BMI range of 17.6-25.6 kg/m^2), but with a more narrow range (more homogeneous) than planned. The range of estimated body fat for these subjects was fairly variable at 14.2-36.2%. The range of observed standard deviations between labs for individual measurements

was 5.43-5.98%. The study design attempted to randomize the order of measures each day and the distribution and order of measuring in each lab is in Table 2. Technician 1 took 13 of the subject measures while the second technician completed the remaining 8 measures. We feel the study followed the original intent of the design well enough to avoid undue influence of potential errors due to the order of sites and technician. Though we did not evaluate for the order of sites, we did evaluate for influence of technician and determined it had no significant influence on the estimated body fat.

Table 2 Randomization of Order of Laboratory Visits

LAB	1st Site	2nd Site	3rd Site
LIL	5	6	10
CCTS	9	8	4
WHAC	7	7	7

The means for the environmental conditions between labs were computed. Temperature between labs demonstrated a strong trend ($p=0.061$) of differences but did not meet the a priori 0.05 threshold. The RH between labs was significantly different ($p = 0.003$). The tests of homogeneity of variances (Levene's statistic) for these variables was performed indicating a significantly different variability between labs in temperature ($p = 0.001$), but the variances in RH between labs was equal ($p = 0.729$). The mean), standard deviation, and ranges for the three sites for %BF, temperature and RH are reported in Table 3. Relative humidity was highest at LIL (mean: 43.47%) with similar yet much lower values at both CCTS (mean: 33.43%) and WHAC (mean: 42.96%) laboratories. Post-hoc analysis of RH by site using the LS means command with Tukey's testing demonstrated that LIL had a significantly higher RH than the CCTS and WHAC facilities. There was no difference between WHAC and CCTS %RH. LIL had a minimum observed temperature (68.7 °F) outside of manufacturer's specifications, while relative humidity outside of the specifications were observed at both CCTS (18.3%) and WHAC (19.8%) facilities.

Table 3 Comparison of Means/SD/Range of Temperature and RH by Site

	Temperature (°F)			% RH		
Lab	Mean	SD	Range	Mean	SD	Range
LIL	73.53	2.82	68.7-77.9	43.47[a]	8.86	33.4-60.0
CCTS	73.56	1.45	71.4-76.1	33.43[b]	9.93	18.3-50.4
WHAC	72.29	1.17	71.0-74.6	34.96[b]	10.83	19.8-51.9

Means with different letters are significantly different $p<0.01$.

SAS evaluation of the data using the general linear modeling procedure (proc GLM) included the subject and lab variables to compare %BF between labs. The model was highly significant at $p < 0.0001$ with $r^2 = 0.985$. Post-testing examination of the means used the least squares means method (LSMEANS) with the Tukey post-hoc test, and are reported in Table 4. There was a significant difference ($p < 0.0001$) in %BF estimates between laboratories (LIL mean, 26.6 ± 5.43; CCTS mean, 24.9 ± 5.98; WHAC mean, 24.8 ± 5.83). The inter-laboratory reliability in BF estimation shows the LIL BodPod is significantly higher than both the CCTS and WHAC devices (see Figure 1). However, the %BF from the CCTS and WHAC pods were not statistically different. Examination of the residuals from this model demonstrated a normal distribution where the p value of the Shapiro-Wilk statistic was 0.3453 demonstrating the normality assumption underlying the general linear model procedure despite a subject number less than 30.

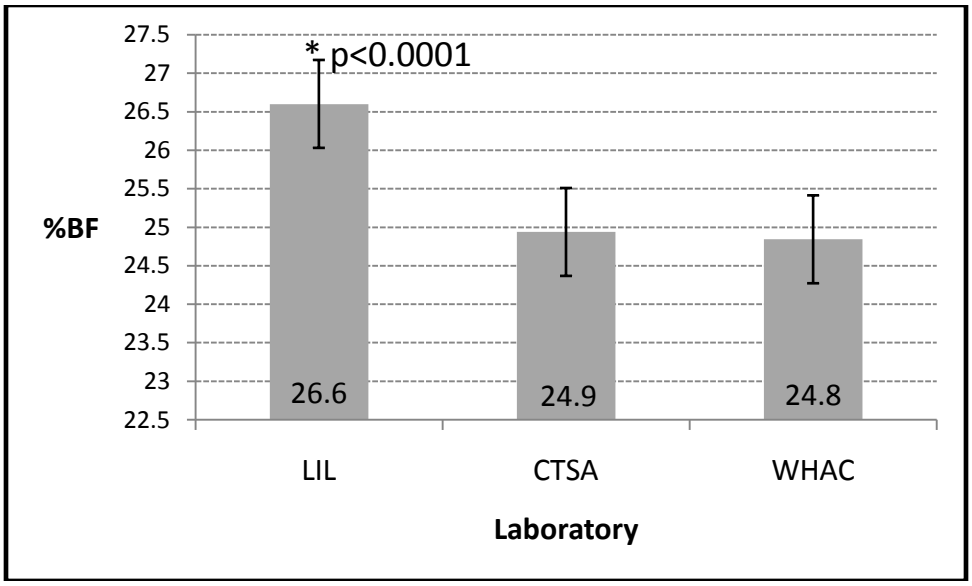
Table 4 %Body fat estimations by lab

	% Body Fat		
Lab	Mean	SD	Range
LIL	26.60[a]	5.43	17.5-35.6
CCTS	24.91[b]	5.98	14.2-36.2
WHAC	24.84[b]	5.83	21.0-34.5

Table 5 Post hoc analysis of %body fat by lab

	Mean %BF	LIL	CCTS	WHAC
LIL	26.6000		< 0.0001	< 0.0001
CCTS	24.9115	< 0.0001		0.9653
WHAC	24.8428	< 0.0001	0.9653	

Figure 1 Mean Body Fat Estimates by Site



To evaluate the influence of possible environmental covariates for %BF prediction, the same general linear model was evaluated adding relative humidity or temperature or both as dependent variables. Neither temperature ($p = 0.3613$) nor humidity ($p = 0.4323$) demonstrated a significant influence on the %BF model. To ensure full evaluation of these possible environmental covariates, a dichotomous variable (met vs. not met)was created from the temperature and relative humidity continuous variables to reflect if the room was within the range of the manufacturer's operating guidelines (70-80 °F and RH of 20-70%). This calculated variable also did not show a significant influence in the model ($p = 0.5091$). The dichotomous variable was evaluated in case there was some sort of threshold effect per the manufacturer's recommendations.

To evaluate which other BodPod measures were potentially responsible for the discrepancies of observed body fat between labs, body weight was examined in a similar modeling routine as the dependent variable. The body weights as measured on the three systems were significantly different, but unexpectedly the differences were between the CCTS and WHAC systems (LIL: mean: 132.29 lb; CCTS: mean: 132.35 lb; WHAC: mean: 132.26 lb). It is interesting to note that relative humidity was a significant covariate ($p = 0.0249$) in modeling of body weight. Temperature did not contribute to the model.

Body density (Db) estimates for each lab were also examined, and the results strongly mirrored the body fat differences. This was not surprising since the machine calculated Db which was then used to compute %BF. Observed estimates for Db had a range of 1.018-1.068 kg/L (standard deviation of 0.0128 kg/L). The highest Db estimates were observed at both CCTS and WHAC with identical values (mean: 1.042 kg/L), while the lowest Db was observed at LIL (mean: 1.039 kg/L). These differences between labs were significantly different ($p < 0.001$), with the LIL BodPod being significantly lower than both the CCTS and WHAC devices. Temperature and RH were then evaluated as potential covariates for the possible influence on Db, and there were no significant influences.

Evaluation of the volume estimates for total body and thoracic gas volumes comprise the numerator in the Db algorithm of the BodPod, thus deserved evaluation. Estimated thoracic gas volume did not present as a significant covariate for the body fat or body density models, but there were differences in these volumes between labs. The older CCTS unit estimated lung volume slightly higher at 3.19 liters with LIL and WHAC units being a bit lower at 3.15 and 3.17 liters respectively. The estimated body volumes were not available from the hardcopy output or the digital file of the older CCTS system, but the LIL and WHAC labs were compared in the GLM model. There was a significant difference ($p < 0.0001$) in body volume estimates between the two laboratories ($r^2 = 0.999$). In the prediction of body volume for these two systems, room temperature trended ($p = 0.0855$) to influence body volume while relative humidity was a significant ($p < 0.001$) predictor of body volume.

Discussion

The inter-laboratory reproducibility in body fat was determined in order to examine the reliability of the BodPod device for both clinical and research applications. There was a significant difference in body fat estimates between laboratories which resulted in BF differences of 1.7 to 1.8% between devices. An additional aim of the study was to identify the potential environmental factors that may influence variation in outcomes. For the prediction of body volume, the primary measure of the BodPod, room temperature trended to predict body volume while relative humidity was a significant predictor of body volume. The observed influence of room temperature on body volume is in agreement with the results reported by Collins [1]. The RH influence on body volume estimates is a novel finding, and continued analysis of this data may support the finding of a more narrow RH range for optimal BF estimation. The results suggest that ambient conditions of temperature and relative humidity may affect BodPod estimations. This study, taken with the Collins study, demonstrated the sensitivity of BodPod units to environmental factors which affect reliability of body fat estimates. The importance of creating a laboratory space for BodPod devices explicitly following manufacturer's specifications for use is likely critical to accuracy of the system. Laboratory spaces should be reevaluated in each lab to ensure stable temperature, relative humidity, and limited air flow (fans, ventilation, and open doorways) in order to limit factors influencing %BF estimates. This same reliability study should be repeated in each laboratory to ensure each machine is functioning within those assumptions on a standardized level.

The results of this study are important for large-scale, *multi-center* studies using BodPods for anthropometric assessments of body composition. The ability to use multiple BodPods interchangeably in research applications will be facilitated by properly controlling environmental factors known to influence body composition estimates. Additionally, each laboratory should strive to document temperature, pressure and relative humidity during measurements in research studies in order to evaluate those factors as possible covariates. For example, our laboratory is currently engaged in a study examining the error between iDXA and BodPod body composition estimates in female runners with inadequate versus adequate skeleton. Documenting the environment as standard protocol is likely important to the data analysis and outcomes of the study.

While reliability for research outcomes is the primary focus of this study, the clinical implications for the interchangeability of BodPod devices is a secondary concern. For an elite level athletic population where multiple BodPods are available, it is common for subjects to use multiple devices over time for their body assessment needs. The ability for such subjects to be able to effectively compare their own results following serial assessments can be strengthened by a tighter regulation of confounding environmental factors and acknowledgement of each machine's independent error range. For instance, if the sports nutrition staff is using the LIL BodPod to measure an athlete's serial body compositions as a way to gauge training outcomes and weight gain/loss goals, staff should know that the LIL BodPod could be 1-2% different than the other two machines on campus and keep the results framed appropriately to the athletes. For athletes involved in weight class sports such as wrestling, the ability to reliably estimate %BF may be viewed as critical to the athlete's weight class goals. For athletes who compete in a lower weight classes than their usual weights, the maintenance of lean mass is critical, and loss of fat mass is usually desired in order to achieve goal weight while maximizing performance. In such cases, the potential difference of 1-2% between serial measurements may be particularly relevant.

Athletes, coaches, and strength coaches favor the use of body composition as one gauge of training program success. When serial assessments reflect a difference within the observed error range (1-2%), it is important to recognize that the athlete did not necessarily gain/lose body fat and that the difference could be due to potential machine error. In addition to controlling for environmental factors like temperature and humidity, it is likely important to encourage athletes to use the same device for serial measures and to frame the results appropriately.

Limitations

Though the study was set up to control for subject-related bias, it is unknown whether subjects complied with 2 hour abstinence from eating, drinking, or exercising as intended. It was anecdotally observed that ambient temperature and relative humidity fluctuations occurred during each session. It would have been beneficial to record these factors for each individual measurement as opposed to once per session. Additionally, we did not measure the barometric pressure in each laboratory, and future studies may consider this in addition to the temperature and humidity. The BodPods tested in this study were not all manufactured in the same year, and were not running the same version of

software. Body volume measurements from the older device at the CCTS laboratory were not readily accessible to the researchers. The ability to obtain the body volume data from all three machines may have strengthened the statistical analysis of the influence of RH on body volume. The pre-test selection of predicting lung volume as opposed to measuring lung volume is another potential limitation of the study, but may have introduced an additional error variable into the data. The predicted lung volume was selected with the intent of assessing body composition in the way that is more common in research and clinical applications as well as to expedite the process. Though it is difficult to control for all potential biases, some of these potential error sources could be better controlled.

Conclusion

The stability of the environment of BodPod laboratories and compliance to operational specifications are likely fundamental to the inter- and intra-device reliability of machine outcomes. The environmental factors, including temperature, pressure and relative humidity, should be documented as part of the measure for future comparisons. Close monitoring and standardization of environmental factors within individual laboratories can also potentially benefit the machine outcomes for future BodPod use in both research and clinical applications. While one of the three ADP devices was found to be significantly different from the other two BodPods, the observed range of machine error was within the acceptable range (1-2%) as determined by the manufacturer, LMI. The best practice for documenting individual progress is to suggest clients use a single device for future measures in order to limit additional machine error in body composition assessments.

More research on the stability of the BodPod unit is necessary to determine an optimal environment for the best reliability. Continued analysis of this data may provide a more narrow range of environmental conditions for reliability. Due to the results of this study, the LIL research group will likely adopt a room protocol for the BodPod lab that ensures a more consistent measuring environment

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